MULTI-OBJECTIVE SPIRAL DYNAMIC ALGORITHMS-BASED FOR A BETTER ACCURACY AND DIVERSITY

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SUPERVISOR’S DECLARATION

I hereby declare that I have checked this thesis and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Algoritma pengoptimuman memainkan peranan penting dalam menyelesaikan banyak masalah kompleks dan masalah dunia sebenar. Penyelesaian yang dijana oleh algoritma mempunyai ketepatan yang tinggi dan boleh diharapkan. Tambahan pula, dengan perkembangan yang pesat dalam bidang teknologi perkomputeran, aplikasi algoritma pengoptimuman dalam menyelesaikan masalah menjadi lebih mudah dan semakin praktikal. Algoritma pengoptimuman juga dikenali sebagai algoritma metaheuristik yang berasal dari pendekatan heuristik. Ia adalah algoritma heuristik yang ditambahnilai dengan strategi yang maju diinspirasikan daripada pelbagai fenomena semulajadi yang ada di bumi. Algoritma ini juga dibahagikan jenis satu-objektif dan berbilang-objektif. Algoritma jenis satu-objektif boleh diaplikasikan untuk menyelesaikan masalah yang mempunyai hanya satu objektif, manakala jenis berbilang-objektif boleh diaplikasikan untuk menyelesaikan masalah yang mempunyai dua objektif. Bagi masalah kompleks yang terdiri dua objektif bercanggah yang tidak dapat diselesaikan dengan algoritma jenis satu-objektif boleh diselesaikan dengan algoritma berbilang-objektif. Penyelesaian yang dihasilkan oleh algoritma ini selalunya dijelmakan dalam bentuk lengkung pendepan-Pareto. Pendepan-Pareto yang dihasilkan adalah ukuran sebaikmana penyelesaian yang dihasilkan oleh algoritma. Ukuran paling utama adalah ketepatan pendepan-Pareto yang dihasilkan dengan pendepan-Pareto yang sebenar dan pengagihan penyelesaian sepanjang lengkung pendepan-Pareto. Setakat ini prestasi algoritma berbilang-objektif masih belum mencapai aras terbaik dalam kedua-dua ukuran tadi. Justeru itu, masih terdapat ruang untuk penambahbaikan dengan memanipulasikan strategi algoritma. Tesis ini menampilkan dua variasi algoritma berbilang-objektif berdasarkan Algoritma Dinamik Lingkaran (SDA) dengan aplikasinya untuk mengoptimumkan pengawal PD bagi Sistem Bandul Terbalik. Variasi yang pertama dipanggil Algorithm Dinamik Lingkaran Berbilang-objektif berstrategi Penyusun Tidak-terdominasi (MOSDA-NS). Variasi ini menggunakan strategi Penyusun Tidak-terdominasi dan Penjarak Kesesakan dengan SDA. Variasi kedua dipanggil Algoritma Berbilang-objektif Dinamik Lingkaran berkonsep-Arkib (MOSDA-A). Ia menggabungkan konsep Arkib dengan SDA. Kedua-dua algoritma yang dibangunkan telah diuji dengan satu set fungsi penanda-aras yang terdiri daripada 10 fungsi berbeza melangkaui pelbagai bentuk lanskap kesesuaian dan ciri. Kedua-dua ukuran ketepatan dan pengagihan penyelesaian pada pendepan-Pareto yang terhasil telah direkodkan. Kemudian, suatu analisa statistik telah dijalankan untuk mengukur tahap penambahbaikan berbanding Algoritma Berbilang-objektif Partikel Berkelompok (MOPSO) dan Algoritma Berbilang-objektif Penyusun Tidak-terdominasi Genetik (NSGAII). Keputusan daripada ujikaji menunjukkan bahawa MOSDA-NS mencapai ketepatan dan pengagihan penyelesaian yang terbaik berbanding dengan semua algoritma yang lain. Daripada segi menyelesaikan masalah dunia sebenar, algoritma yang dibangunkan telah diaplikasi untuk mengoptimumkan dua pengawal PD bagi Sistem Bandul Terbalik. Pengawal PD yang pertama adalah untuk menyingkirkan kesilapan yang terhasil daripada pergerakan linear bagi kereta bergerak manakala pengawal PD yang kedua menyingkirkan kesilapan darjah pusingan bagi bandul terbalik. Tindakbalas bagi kedua-dua darjah pendulum dan posisi kereta dalam domain masa telah direkodkan. Suatu analisa untuk mengukur prestasi tindakbalas kemudiannya dijalankan untuk mengetahui kesilapan keadaan-mantap, peratusan kelebihan-pecutan, masa kenaikan dan masa penyelesaian. Penemuan daripada analisa ini menunjukkan algoritma-algoritma yang baru dibangunkan ini mempunyai prestasi pengawalan yang lebih baik jika dibandingkan dengan MOPSO dan NSGAII.

ABSTRACT

Optimization algorithm plays an important role in solving many complex and real-world problems. Solution offers by the algorithm has high accuracy and reliable. Moreover, with the fast development in computing technology, application of optimization algorithm in solving problems is easier and becomes more practical. Optimization algorithm is also known as a metaheuristic algorithm which is originally come from heuristic approach. It is a heuristic algorithm that is integrated with an advance strategy inspired from many natural phenomena found on earth. The algorithms can be categorized into a single objective and a multi-objective type. Single objective type optimization algorithm can be applied to solve a problem with a single objective. On the other hand, multi-objective algorithm is applicable to solve a problem with two or more objectives. A more complex problem in which has two conflicting objectives where it is not solvable by the single objective type algorithm is the right type of problem for the multi-objective algorithm. Solution produced by the multi-objective algorithm is always presented in Pareto front curve representation. The produced Pareto front curve is a measure of how good the solution produced by the algorithm is. The main measurement criteria include the accuracy of the solution to the actual Pareto curve and the distribution of the found solution on the actual Pareto curve. Yet the performance of many multi-objective algorithms in terms of the accuracy and the distributed solution is not achieved at the highest performance level. There are still rooms for improvement the algorithm performance by manipulating the algorithm strategy. This thesis presents two variants of multi-objective type algorithms based on a Spiral Dynamic Algorithm (SDA) with application to optimize a Proportional-Derivative (PD) controller for an Inverted Pendulum System. The first variant is known as a Nondominated Sorting Multi-objective Spiral Dynamic Algorithm (MOSDA-NS). It is a strategy which combines a Nondominated Sorting and Crowding distance approaches with the SDA. The second variant is known as Archived-based Multi-objective Spiral Dynamic Algorithm (MOSDA-A). It is a strategy combining an Archived approach with the SDA. All the developed algorithms were tested with a set of benchmark functions comprising of 10 different functions covering various fitness landscapes and features. Both accuracy performance and distribution of the found solution on the obtained Pareto front are recorded. A statistical analysis is then conducted via a Wilcoxon Sign Rank test and a Friedman test. Both tests are conducted to verify the significant improvement of the solution obtained via the proposed algorithms to the Multi-objective Particle Swarm Optimization (MOPSO) and Multi-objective Nondominated Sorting Genetic Algorithm II (NSGAII). Result from the test shows that the proposed MOSDA-NS achieved the best accuracy and distribution performances compared to all other algorithms. In terms of solving a real-world problem, the proposed algorithms are applied to optimize two different Proportional-Derivative (PD) controllers for an Inverted Pendulum system attached on a moving cart. The first PD controller attenuates error for a linear movement of the moving cart. The second PD controller eliminates error for a rotating angle of the inverted pendulum. Transient responses of both pendulum angle and cart position in time-domain representation are recorded. An analysis on the transient responses is then conducted which measuring steady-state error, percentage overshoot, rise time and settling time. Finding of the analysis indicates that the proposed algorithms have resulted in a better control performance compared to the MOPSO and NSGAII.

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LIST OF ABBREVIATIONS

2LP	Bi-level programming
AM	Archiving method
AMGA	Archived-Based Micro Genetic Algorithm
APAES	Adaptive Strategy PAES
BA	Bat algorithm
BE	Bat Echolocation
BP	back-propagation algorithm
CF	Community Fitness
CS	Community Score
DE	Differential evolution
DMD	Diversity Metric Delta
DSD	directed search domain
EA	Evolutionary algorithm
EMO	Evolutionary Multi-Objective Optimization
GA	Genetic Algorithm
GD	Generational Distance
GP	Goal programming
HEM	hybridization-encouraged mechanism
HSCDA	Hybrid Self-Adaptive Algorithm
HV	Hypervolume Indicator
IP	Inverted pendulum
IWF	Inertia Weighting Factor
KKM	Kernel k-Means
LM	Lexicographic method
MCDA	Multi-objective Community Detection Algorithm
MCDM	Multi-Criteria Decision Making
MGA	Micro Genetic Algorithm
MLP	Multi-level programming
MLPSO	Multi-Leader PSO
MO	Multi-objective
MOA	multi-objective Algorithm
MOBA	Multi-Objective BA
MODE	Multi-Objective Differential Evolutionary
MOGA	Multi-objective Genetic Algorithm

MOO	Multi objective Optimization
MOP	Multi-objective Problem
MOPSO	Multi-Objective Particle Swarm Algorithm
MOS	Metric of spacing
MOWCA	Multi-objective Water Cycle Algorithm
MPB	Mathematical-Programming-Based
NBI	normal boundary intersection
NBIm	modified normal boundary intersection
NC	normal constraint
NDS	Non-dominated solution
NPF	No-Preference Methods
NPGA	Niched-Pareto Genetic Algorithm
NS	Non-dominated sorting method
NSGA	Non-dominated Sorting Genetic Algorithm
NSGAII	Fast Elitist Non-Dominated Sorting Genetic Algorithm
NSGSA-CM	Non-Dominated Sorting Gravitational Search Algorithm with Chaotic Methodology
OPSO	Orthogonal PSO
PAES	Pareto Archived Evolutionary Strategy
PD	Proportional-Differential
PESA	Pareto Envelope Based Selection Algorithm
PF	Pareto-front
PM	Priori method
PoM	Posteriori Method
POS	Pareto optimal solution
PSO	Particle Swarm Algorithm
RANSAC	Random Sampling Consensus
RC	Ratio Cut
SDA	Spiral Dynamics Algorithm
SKF	Simulated Kalman Filter
SO	Single-objective
SOA	single objective Algorithm
SOO	Single-objective Optimization
SOP	Single-objective Problem
SPEA	Strength Pareto Evolutionary Algorithm
SPEAII	strength Pareto EA II

SPO	Successive Pareto Optimization
STWA	Sliding Time Window Algorithm
TBP	Three-Term Backpropagation
UOF	Unique objective function
VEGA	Vector Evaluated Genetic Algorithm
WCA	Water Cycle Algorithm

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